

# X-RAY REFLECTIONS ON AGN

A.C. Fabian

Institute for Astronomy, Madingley Road, Cambridge CB3 0HA, UK

## ABSTRACT

X-ray reflection generates much of the spectral complexity in the X-ray spectra of AGN. It is argued that strong relativistic blurring of the reflection spectrum should commonly be expected from objects accreting at a high Eddington rate. The good agreement found between the local density in massive black holes and the energy density in quasar and AGN light requires that the accretion which built massive black holes was radiatively efficient, involving thin discs extending within 6 gravitational radii. The soft excess found in the spectra of many AGN can be explained by X-ray reflection when such blurring is included in the spectral analysis. Some of the continuum variability and in particular the puzzling variability of the broad iron line can be explained by the strong light bending expected in the region immediately around a black hole. Progress in understanding this behaviour in the brightest sources can be made now with long observations using instruments on XMM-Newton and Suzaku. Future missions like Xeus and Con-X, with large collecting areas, are required to expand the range of accessible objects and to make reverberation studies possible.

## 1. INTRODUCTION

In this brief review, I consider the spectra and spectral variability of unobscured Active Galactic Nuclei such as Seyferts and quasars. They typically have the spectral components identified in Fig. 1, namely a) an underlying power-law, b) a soft excess above the power-law at low energies below 1 keV, c) an iron line (which may have a broad component), and d) a Compton hump. Traditionally these components have been considered as a) thermally Comptonized soft photons originating from b) thermal (blackbody) emission from an optically-thick accretion disc about the central black hole, together with the line c) and Compton-scattered d) parts of X-ray reflection from that disc or more distant matter. An important parameter when model-fitting such sources is the inner radius of the accretion disc, which determines how much relativistic blurring is applied to the reflection com-

ponents. It is often assumed to be greater than 6 gravitational radii ( $6r_g = 6GM/c^2$ ) around the black hole, which is the innermost stable circular orbit around a non-spinning Schwarzschild black hole. Spectral deviations from this picture are often taken into account by adding additional emission and/or absorption components, some of which cover only part of the source.

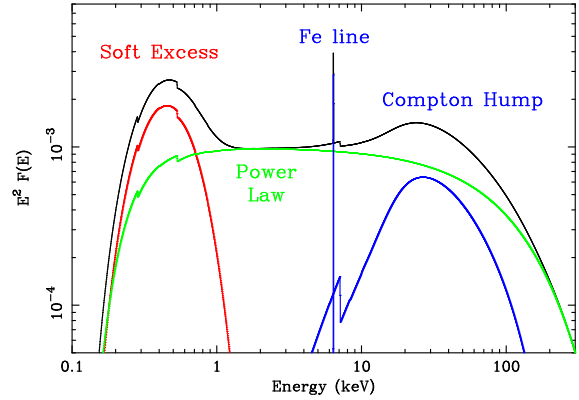


Figure 1. Model X-ray spectrum of an AGN. Galactic absorption causes the flux to decrease steeply below 0.3 keV.

There are problems with this traditional picture which suggest that it is at least incomplete. For several well-studied sources there are modifications to the above model which seem to fit the data, in particular the spectral variability, better. The main modification is to allow the inner radius of the disc to go to  $2r_g$ , meaning the black hole is spinning. This introduces the possibility of very strong gravitational effects on the spectrum. The second consideration is to allow the atomic abundances to be different from the solar value. A more detailed review is given in Fabian & Miniutti (2005).

Note that most bright AGN *must* have a radiatively efficient accretion flow or the Soltan (1982) argument relating the energy density of accretion radiation and the local mean density in black holes would yield a low efficiency. The good agreement between the observations of quasar/Seyfert light and local black holes with an accretion efficiency of at least 10 per cent (Yu & Tremaine 2002; Fabian 2003; Marconi et al 2004) strongly argues for radiatively efficient flows with an inner disc radius

within  $6r_g$ . The agreement, at all mass ranges, would not happen if the discs in quasars and luminous Seyfert galaxies stopped at several tens of  $r_g$  or indeed larger than  $6r_g$ . Any power lost in winds and jets only strengthens these arguments. Massive black holes in galactic nuclei are likely to be rapidly spinning (Volonteri et al 2004) so small disc inner radii should be the norm and we should seriously consider that much of the X-ray emission from objects accreting at a high ( $\gg 0.01$ ) Eddington fraction emerges from within a few  $r_g$ .

## 2. THE PROBLEMS

### 2.1. The soft excess

Several studies culminating in the work of Gierlinski & Done (2004) show that the temperature of the excess emission, if characterized as blackbody, seems to be the same in systems where the accretion rates and/or masses differ by several orders of magnitude. This is not expected from an accretion disc.

### 2.2. The iron line

Many sources show a narrow iron line component which is undoubtedly due in many cases to reflection on distant gas. Broad components, as expected from reflection by the inner accretion disc, are seen, but are not always present or at least not evident. Such components can sometimes be fitted away with partial-covering models.

### 2.3. Variability

Where sources are highly variable so that the emission region must be very small, partial covering models present physical problems for understanding the geometry of the situation. Only very occasionally can we be in a preferred line of sight; the covering material has to be randomly placed. What this matter is, where it lies and why it only partly covers the source are unknown.

### 2.4. Iron line variability

MCG-6-30-15 has a robust broad iron line (Tanaka et al 1995; Wilms et al 2001; Fabian et al 2002). Chandra grating observations and RXTE data have sufficient resolution and coverage to rule out partial covering solutions (Young et al 2005). A problem emerges with the lack of variability seen in the line, if the effects of strong gravity are ignored. The strength of the iron line should follow the brightness of the power-law component, but it does not. The iron line does vary on short timescales but not in any simple manner (Iwasawa et al 1996, 1999; Nandra & Edelson 2000; Matsumoto et al 2002; Fabian et al 2002).

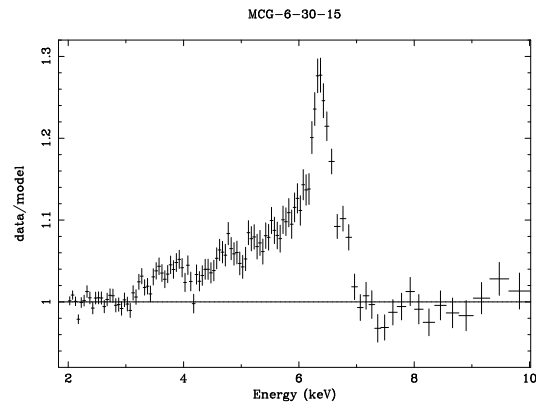


Figure 2. The broad iron line seen in the XMM-Newton spectrum of MCG-6-30-15 (see Fabian et al 2002; this spectrum was produced from reprocessed data by S. Vaughan).

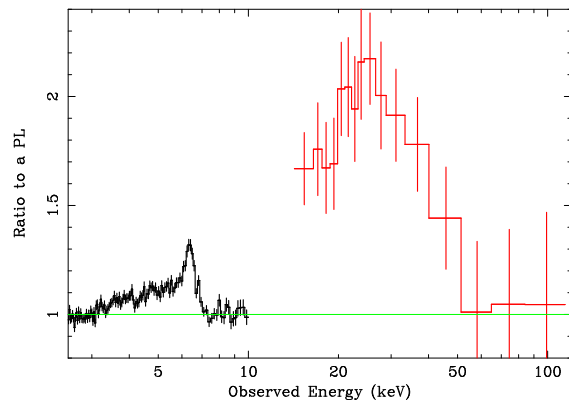


Figure 3. The iron line and Compton hump in MCG-6-30-15 shown as deviations from a simple power-law spectrum. The data below 10 keV are from XMM-Newton and the data above from BeppoSAX (kindly prepared by G. Miniutti).

## 3. THE TWO-COMPONENT MODEL OF SPECTRAL VARIABILITY

A simple phenomenological model which fits the spectral variability of several bright Seyferts well has two main components (McHardy et al 1998; Shih et al 2001; Fabian & Vaughan 2003). A simple power-law description of the spectrum often shows the source to be harder when faint and softer when bright. The photon index of the source may limit to some fixed value at the highest fluxes. This behaviour can be modelled well in terms of two components; a soft power-law of fixed spectral index and variable intensity plus a hard component which varies little. The model accounts for the rms variability spectrum and spectral behaviour of many sources.

The shape of the quasi-constant hard component can be extracted in several ways, using a) flux-flux plots in which the flux in various energy bands is correlated with the flux in another band (say 1–2 keV) with the con-

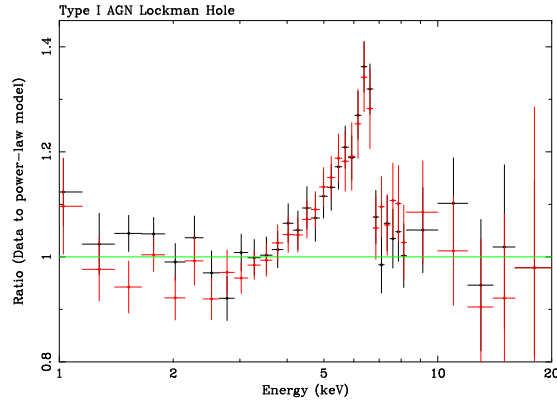


Figure 4. Broad iron line seen in the rest-frame shifted, summed spectra of 51 Seyfert 1 galaxies in the XMM-Newton observations of the Lockman Hole (Streblyanska et al 2005).

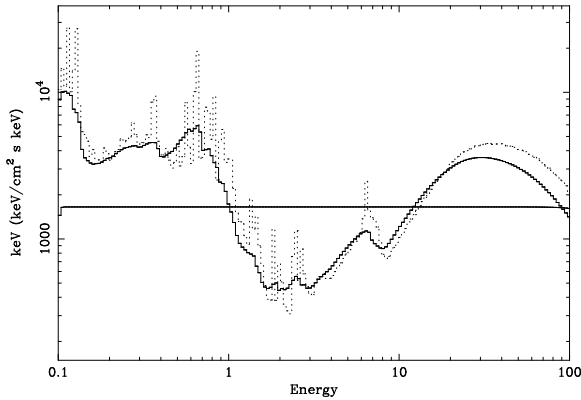


Figure 5. Two-component model. The horizontal line is the power-law component which varies significantly in amplitude. The solid curved line is the relativistically-blurred reflection spectrum (shown dotted).

stant component appearing as the intercept (e.g. Taylor et al 2004); b) difference plots where the spectrum of the faintest flux state is subtracted from that of the brightest (Fabian et al 2002); or c) straight model fitting (Vaughan et al 2004). When applied to MCG–6–30–15 all these methods indicate that the hard component has the shape of blurred reflection and the variable soft component is a power-law. Similar results are found for NGC 4051 (Ponti et al 2005).

#### 4. SOLUTIONS INVOLVING STRONG GRAVITY

An alternative interpretation of the soft excess, hinted at in earlier papers (Czerny et al 2003; Ross & Fabian 2005) is for it to be the blurred soft part of the ionized reflection spectrum. This has been tested by Crummy et al (2005) and generally found to give better fits to spectra of PG quasars and various Seyferts than a simple blackbody disc does. The reflection spectrum needs to be significantly blurred, requiring that much of the emission arises from

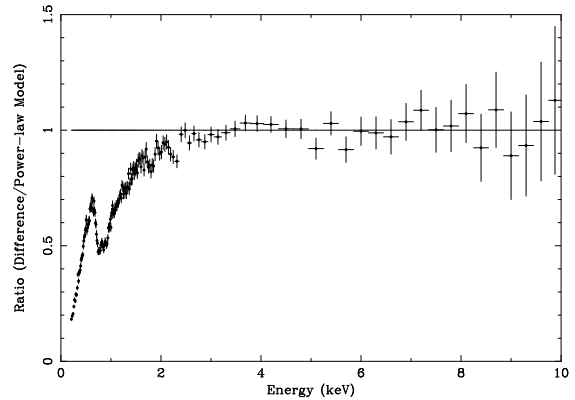


Figure 6. Difference spectrum from MCG–6–30–15 (Turner et al 2004). It shows the ratio of the spectrum, made by subtracting low from high flux data, to a simple power-law. Note that it has no broad iron line and shows that the component which varies is a simple power-law in the 3–10 keV band). Assuming that it remains a power-law to low energies, the deviations there show the absorption components (mostly due to a warm absorber).

near the centre of an accretion disc about a spinning black hole. The blurred reflection spectrum has a ‘boxy’ shape better suited to the soft excess than a blackbody which then requires fewer, if any, additional absorption components for a good fit.

The iron abundance needs also to be a free parameter. Extreme blurring together with low iron abundance can make most broad iron lines undetectable with current instruments.

If much of the X-ray emission emerges from the innermost parts of the disc around a spinning black hole then light bending needs to be taken into account. This has a strong effect on the brightness of the primary power-law source, making it appear faint to a distant observer when it is close to the hole and bright when further away. Some of the variability of the power-law continuum can thus be due to the position of the source relative to the hole, rather than any intrinsic effect. The strong light bending causes much of the flux variability.

Consider a constant power-law source which is brought down the spin axis from  $20$  to  $1r_g$ . It would appear to an observer seeing the disc at an inclination of say  $30$  degrees to decrease dramatically in flux. The reflection component would however change little until the source is below about  $4r_g$ . Although the reflection is becoming more concentrated at the centre of the disc the increase in power-law flux bent down onto the disc compensates for any loss of flux.

This ‘light-bending’ model (Miniutti et al 2003, 2004) is a simple consequence of strong gravity close to the black hole and predicts effects that have to be taken into account.

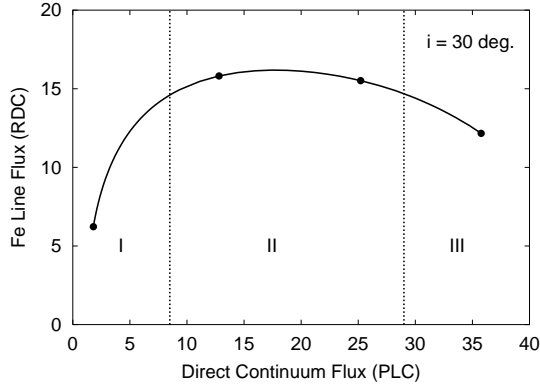


Figure 7. The response of the reflection component (RDC) to the power-law continuum (PLC) in the light bending model. The height of the PLC above the hole is 20, 10, 5 and  $1r_g$  at the 4 marked points on the curve going from right to left.

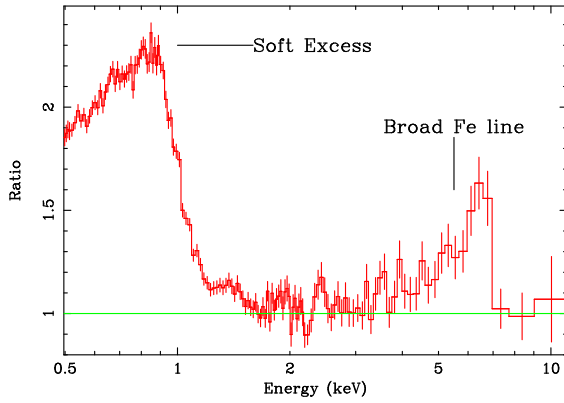


Figure 8. The XMM-Newton spectrum of 1H0707 shown as the ratio to a power-law fitted in the 2–3 and 8–10 keV energy bands. The spectral features resemble blurred reflection, although absorption models can be made to fit (Boller et al 2002).

## 5. APPLICATIONS TO A RANGE OF SOURCES

The light-bending model has been applied to an increasing range of AGN, particularly NLS1 (MCG–6–30–15, Fabian & Vaughan 2003; NGC 4051, Ponti et al 2005; 1H0707, Fabian et al 2004; 1H0439, Fabian et al 2005) and at least one Galactic Black Hole (GRO J1650, Rossi et al 2005). Future challenges are to see whether it fits just a class of AGN or its relevance is more widespread.

Is it consistent, for example, with the variable, red or blue-shifted, emission features occasionally seen in some objects (e.g. NGC 3516, Iwasawa et al 2004)? A possibility in those cases is that indeed most of the primary emission arises from close to the centre of the disc but, due to the rapid rotation there, it is beamed along the disc and illuminates transient ‘bumps’ or waves on the surface of the disc, causing transient reflection there.

What we need to do next is to see whether the reflec-

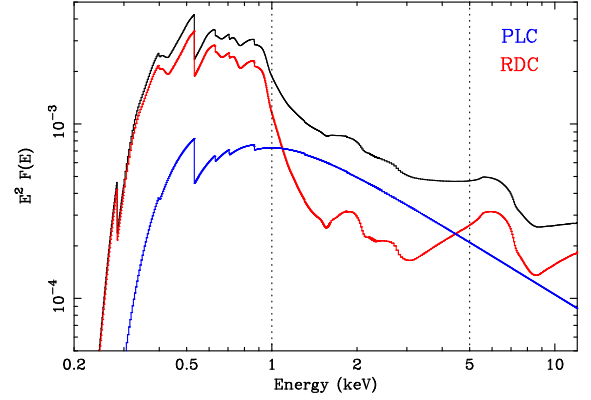


Figure 9. The spectral components in the 2 component model for 1H0707 (Fabian et al 2002). In this state the power-law component dominates the spectrum in the 1–5 keV band.

tion does follow the variation expected to occur as the power-law continuum moves and varies (Fig. 7). Subtle changes are expected in the degree of extreme blurring which occurs when the power-law source is closest to the black hole. This requires more data from the parts of the lightcurve when the flux is low. These occur infrequently but are accessible in MCG–6–30–15 by long observations with XMM-Newton and Suzaku. Testable variations of the reflection from the strong gravity regime around black holes should be detectable now with long dedicated observations.

On the longer term we look to the next generation of detectors to measure the reverberation of the reflection. This needs to be done in a light crossing time and requires a large collecting area. AGN detect 100s of times more photons per light crossing time than Galactic black holes so are the preferred targets. At a flux of about 2 photon per square metre per second from the brightest iron lines, this requires a collecting area of at least two square metres at 6 keV. We look forward to such observations with Xeus and Con-X.

## ACKNOWLEDGMENTS

I thank Giovanni Miniutti for help and discussion and the Royal Society for support.

## REFERENCES

- [26] Boller T., et al 2002, MNRAS, 329, L1
- [26] Crummy J.C., Fabian A.C., Gallo L., Ross R.R., 2005, MNRAS, submitted
- [3] Czerny B., Nikolajuk M., Różańska A., Dumont A.-M., 2003, A&A, 412, 317
- [4] Fabian A.C., et al. 2002a, MNRAS, 335, L1

- [5] Fabian A.C., Vaughan S., 2003, MNRAS, 340, L28
- [6] Fabian A.C., Miniutti G., Gallo L., Boller Th., Tanaka Y., Vaughan S., Ross R.R., 2004, MNRAS, 353, 1071
- [7] Fabian A.C., Miniutti G., Iwasawa K., Ross R.R., 2005, MNRAS in press, astro-ph/0504472
- [26] Fabian A.C., 2003, astro-ph/0304122
- [26] Fabian A.C., Miniutti G., 2005, astro-ph
- [26] Gierlinski M., Done C., 2004, MNRAS, 349, L7
- [11] Iwasawa K., Fabian A.C., Mushotzky R.F., Brandt W.N., Awaki K., Kunieda H., 1996, MNRAS, 279, 837
- [12] Iwasawa K., Fabian A.C., Young A.J., Inoue H., Matsumoto C., 1999, MNRAS, 307, 611
- [13] Iwasawa K., Lee J.C., Young A.J., Reynolds C.S., Fabian A.C., 2004, MNRAS, 347, 411
- [26] Marconi A., Risaliti G., Gilli R., Hunt L.V., Maiolino R., Salvati M., MNRAS, 351, 169
- [26] Matsumoto C., Inoue H., Fabian A.C., Iwasawa K., 2003, PASJ,
- [26] McHardy I.M., Papadakis I.E., Uttley P., 1998, Nucl. Phys. B, 69, 509
- [17] Iwasawa K., Miniutti G., 2004, Progr. Theor. Phys., S155, 247
- [18] Iwasawa K., Miniutti G., Fabian A.C., 2004, MNRAS, 355, 1073
- [19] Miniutti G., Fabian A.C., Goyder R., Lasenby A.N., 2003, MNRAS, 344, L22
- [20] Miniutti G., Fabian A.C., 2004, MNRAS, 349, 1435
- [26] Ponti G., et al 2005, MNRAS submitted
- [22] Reynolds C.S., Wilms J., Begelman M.C., Staubert R., Kendziorra E., 2004, MNRAS, 349, 1153
- [23] Ross R.R., Fabian A.C., 2005, MNRAS, 358, 211
- [24] Rossi S., Homan J., Miller J.M., Belloni T., 2005, MNRAS, 360, 763
- [26] Soltan A., 1982, MNRAS, 200, 115
- [26] Yu Q., Tremaine S., 2002, MNRAS, 335, 965
- [27] Shih D.C., Iwasawa K., Fabian A.C., 2001, MNRAS, 333, 687
- [28] Streblyanska A., Hasinger G., Finoguenov A., Barcons X., Mateos S., Fabian A.C., 2005, A&A, 432, 395
- [29] Tanaka Y., et al 1995, Nature, 375, 659
- [30] Taylor R.D., Uttley P., McHardy I.M., 2003, MNRAS, 342, L31
- [31] Turner A.K., Fabian A.C., Vaughan S., Lee J.C., 2003, MNRAS, 346, 833
- [32] Turner A.K., Fabian A.C., Lee J.C., Vaughan S., 2004, MNRAS, 353, 319
- [33] Vaughan S., Edelson R., 2001, ApJ, 548, 694
- [34] Vaughan S., Fabian A.C., Nandra K., 2003, MNRAS, 339, 1237
- [35] Vaughan S., Fabian A.C., 2004, MNRAS, 348, 1415
- [36] Vaughan S., Fabian A.C., Ballantyne D.R., de Rosa A., Piro L., Matt G., 2004, MNRAS, 351, 193
- [37] Volonteri M., Madau P., Quataert E., Rees M.J., 2005, ApJ, 620, 69
- [38] Wilms J., et al., 2001, MNRAS, 328, L27
- [39] Young A.J., Lee J.C., Fabian A.C., Reynolds C.S., Gibson R.R., Canizares C.R., 2005, ApJ, 631, 733